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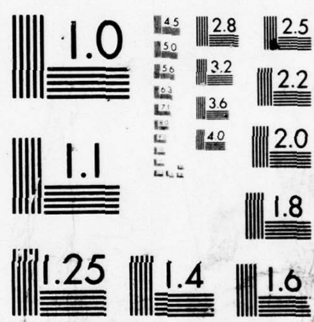

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THE ROLE OF OPERATIONAL SATELLITES IN THE AVIATION WEATHER SYSTEM

C. L. Bristor

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DEPARTMENT OF TRANSPORTATION • UNITED STATES OF AMERICA

SEPTEMBER 1978
FINAL REPORT

Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161.

Prepared for

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16. Abstract

Current operational weather satellite capabilities are briefly reviewed and then projected into the 1980s in terms of their potential impact on the Aviation Weather System (AWES). The role of geostationary satellites is emphasized. On the basis of near term commitments and on planning already underway toward further developments in the late 1980s, one can project important growth in such impact. Developmental factors include: improved sensing in more spectral channels at higher space-time resolution; progress in the extraction of quantitative observables from basic digital sensor data; increased attention to the needs of the very short range weather "nowcaster"; and technological advances which offer more cost-effective means for display and assimilation of satellite data into AWES. Specific recommendations are made.

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METRIC CONVERSION FACTORS

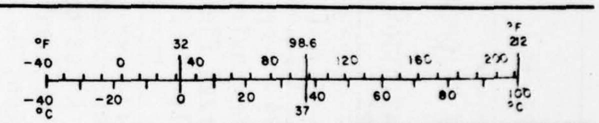
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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Executive Summary

Over the past several years, information from operational weather satellites--particularly the imagery from geostationary satellites -- has assumed an increasingly important role in the very short range forecasting of severe local storms. The impact of satellites on the so-called "nowcasting" of hazardous flying weather is already being realized as air route control centers are provided with half hourly images from GOES (Geostationary Operational Environmental Satellites). Projecting present plans for the upgrading of the FAA Aviation Weather System (AWES), by 1980 some thirty sites (Air Route Traffic Control Centers, ARTCC, and Flight Service Stations, FSS) will have such image acquisition capabilities, and the important question arises: Are further resource commitments necessary in order to maximize the impact of satellites on AWES, and, if so, what are the most cost-effective steps to be taken? There are, indeed, important trends in operational weather satellite development which suggest substantially improved support for aviation weather, but one must also project trends in sensor development, data manipulation, product dissemination, and technology advancements at the user interface before addressing recommendations for AWES.

Since GOES provides constant surveillance, growth in geostationary satellite operations is a prime consideration. The next spacecraft in the present series will include an augmented sensor package called VAS (Visible-Infrared Spin Scan Radiometer (VISSR) Atmospheric Sounder). It will be positioned near 95°W longitude and operated as a third experimental satellite in support of severe storm nowcasting. More frequent imagery will be provided over weather threat areas permitting the extraction of cloud tracer wind vectors, the measurement of temperature trends in convective storm developments, and the monitoring of other important weather trends in fine spatial scale. Meso scale arrays of atmospheric soundings will also be produced at frequent intervals (3 or 4 hours). With present plans projecting a continuing operational test, one may speculate that a three-geostationary satellite configuration may become fully operational in the early eighties. Continuous support then provided for the monitoring of hazardous flying weather developments would require advanced means for assimilating the more frequent imagery, soundings and other derived products.

In the case of polar orbiting satellites, nowcasting support is available only on an intermittent basis. Even so, improved sounding and imaging sensors on NOAA's TIROS-N and the Defense Meteorological Satellite Programs's Block 5D series can

provide important additional inputs, each on a four-time-per-day schedule. Multi channel imaging at 1 km or better, plus compound sounders having added microwave sensing, promise improved indirect sensing operations from both systems by 1980.

NOAA and NASA experts are already engaged in planning an integrated new polar/geostationary weather satellite system for the late eighties. Still higher resolution sensing -- particularly from geostationary altitude -- plus greater use of microwave sensors and the inclusion of weather radar on polar orbiters are all possibilities for this future operational system.

In the area of data reduction and automated product extraction, lower cost and more powerful computers (including image manipulating array processors) will provide the means for assimilating the increasing data bulk. Many developmental algorithms will provide the basis for operational programs, but much additional software will be required to blend satellite inputs with other information into immediate response indicators for nowcasting support.

As for satellite information dissemination, compressed extractions will become increasingly available via AFOS, NADIN, or other relatively low bandwidth landline circuits. But, basic image data, such as now available through GOES-TAP, will be required in increasing amounts and in higher fidelity digital form. Direct linkage by satellite ground stations shows promise of providing such service.

Technological advancements in interactive processing systems are suggesting the means for human assessment and assimilation of nowcasting indications obtained from prediction models and from other automated information manipulation resources. Such advanced systems can also facilitate the monitoring and updating of resulting predictions through rapid visual intercomparison of projected trends and up-to-the-minute validating data. Lower cost, high density, on-line storage devices will provide rapid access to the voluminous on-line data base. Manipulating software, plus flexible CRT display with flexible refresh storage, will then permit animation and juxtaposition or superposition of various predictor fields for easy and rapid intercomparison.

There is need to monitor these continuing developments during the next few years as the Center Weather Service Units (CWSU) and the GOES-TAP service achieve a mature operational status. By 1980 the improving satellite source data and concurrent information extraction advancements will begin to indicate the more obvious steps to be considered for the further improvement of AWES. On the basis of more detailed considerations developed in this study, the following are recommended:

1. Establish a weather satellite unit within the FAA's Systems Research and Development Service to serve as a responsible focal point for the monitoring of satellite advancements and for the generating and updating of satellite-related requirements for the further improvement of the Aviation Weather System.

2. Consider an interactive forecasting facility with advanced animated display capabilities as a primary means for the integration of indications from prediction models, weather radars, in situ observational data, and all satellite inputs for continuously updated 0-4 hour short range predictions. Such support would be dedicated to flight planning and other strategic aviation operations.

3. For imminent threat situations requiring 0-30 minute nowcasting support, consider software and hardware embellishments of the interactive animated system which will provide immediate nowcasting support superior to present subjective and persistence-type projections.

4. From the proposed Satellite Unit, develop more active ties with the operational satellite community including:

   - Cooperative arrangements with NOAA's Satellite Service whereby product extractions in support of aviation weather can be more specifically stated and, hopefully, supported by resource commitments.

   - Closer association with satellite information extraction activities at the Air Force Global Weather Central -- particularly with respect to their 3-D nephanalysis operation and other continuously updated aviation weather-related data base activities.

   - More directed monitoring of applications-oriented weather satellite developments at the Goddard Space Flight Center and at the universities with emphasis on interactive hardware systems and data manipulating software directly applicable to aviation weather.

Acronyms and Abbreviations

ADCCP	Advanced Digital Communications Control Procedures
AFGWC	Air Forces Global Weather Central
AFOS	Automation of Field Operations and Services
AOIPS	Atmospheric-Oceanographic Information Processing System
APT	Automatic Picture Transmission
ARTCC	Air Route Traffic Control Center
ASDAR	Aircraft-Satellite Data Relay
ATS	Advanced Technology Satellite
AVHRR	Advanced Very High Resolution Radiometer
AWES	Aviation Weather System
CDA	Command and Data Acquisition (station)
CONUS	Continental United States
CRT	Cathode Ray Tube
CWSU	Center Weather Service Unit
DCPLS	Data Collection and Platform Location System
DCPRS	Data Collection Platform Radio Set
DCS	Data Collection System
DMSP	Defense Meteorological Satellite Program
DoD	Department of Defense
D/RADEX	Digital Radar Experiment
EFAS	Enroute-Flight Advisory Service
ESA	Eurepean Space Agency
ESDAS	Environmental Satellite Data Access System
FAA	Federal Aviation Administration
FB4	Federal Building 4 (Suitland, MD)
FSS	Flight Service Station
GOES	Geostationary Operational Environmental Satellite
GOES-TAP	GOES landline image distribution system
GSFC	Goddard Space Flight Center
HIRS	High resolution Infrared Radiation Sounder
HRPT	High Resolution Picture Transmission
IR	Infrared
ITOS	Improved TIROS Operational Satellite
IVAMS	Innovative Video Applications in Meteorology
Laserfax	Laser facsimile recorder (Harris Corp.)
MAPS	Meteorological and Aeronautical Presentation System
METEOSAT	Meteorological Satellite
MMIPS	Man-Machine Interactive Processing System
MSU	Microwave Sounder Unit
NASA	National Aeronautics and Space Administration
NADIN	National Airspace Data Interchange Network
NDC	National Distribution Circuit
NEDS	Navy Environmental Display System
NESS	National Environmental Satellite Service
NHC	National Hurricane Center
NMC	National Meteorological Center
NOAA	National Oceanic and Atmospheric Administration
NSSFC	National Severe Storm Forecast Center
NWS	National Weather Service
OLS	Operational Line Scan system
Pixel	Picture element
PVD	Plan View Display

RADAP	Radar Data Processor
SAMSO	Space And Missile Systems Organization
SASS	SEASAT-A Scatterometer System
SCOMS	Subcommittee on Operational Meteorological Satellites
SEASAT	Oceanographic satellite
SEIDS	Satellite Environmental Interactive Display System
SFSS	Satellite Field Service Station (NOAA/NESS)
SMMR	Scanning Multifrequency Microwave Radiometer
SMS	Synchronous Meteorological Satellite
SR	Scanning Radiometer
SSM/I	Special Sensor Microwave Imager
SSM/T	Special Sensor Microwave Temperature (sounder)
SSU	Stratospheric Sounder Unit
STORMSAT	Severe storm satellite (planned)
TBM	Terabit Memory system
TDL	Techniques Development Laboratory (NWS)
TDRSS	Tracking and Data Relay Satellite System
TIROS	Television-Infrared Observation Satellite
TOVS	TIROS Operational Vertical Sounder
TPT	Television Picture Terminal
TSO	Time Sharing Operation
VAS	VISSR Atmospheric Sounder
VDB	VISSR Data Base
VHRR	Very High Resolution Radiometer
VIRGS	Visible and IR Gridding System
VISSR	Visible Infrared Spin Scan Radiometer
VSDS	Video Satellite Display System
VTPR	Vertical Temperature Profile Radiometer
WEFAX	Weather Facscimile Experiment
WWB	World Weather Building

THE ROLE OF OPERATIONAL SATELLITES IN THE AVIATION WEATHER SYSTEM

1.0 BACKGROUND

The current preliminary plan for improving the Aviation Weather System (AWES) cites the need for support from weather satellites in several functional categories. The present purpose is to expand upon these support requirements, first, through an in-depth description of current and near term satellite capabilities, followed by a discussion of downstream improvements already budgeted, and finally, by projecting more advanced possibilities now under consideration for the late 1980s. Coupled with the discussion of potential satellite support is consideration of a variety of communication and information access capabilities along with a discussion of data manipulation requirements to maximize impact on AWES. Hardware and software requirements are also described in terms of functional needs, and, finally, satellite capabilities are summarized in terms of several recommendations.

The role of geostationary satellites is emphasized because of their constant surveillance capabilities, but potential for added support from polar orbiters is also discussed. Only satellites with realtime service commitments are considered. Introductory comments deal mainly with the recent past with emphasis on aspects relative to aviation weather.

1.1 Recent Geostationary Satellite Developments

Spin scan imagery from NASA's Advanced Technology Satellites (ATS), launched in 1966 and 1967, provided the first cloud pictures from geostationary altitude. Experimental operations involving Mercator and polar stereographic mapping, animation, cloud tracer wind estimating, and various gray scale enhancements, all provided the impetus for an operational system. With the launch of NASA's Prototype Synchronous Meteorological Satellites (SMS 1 and 2) in 1974 and early 1975, and with NOAA's Geostationary Operational Environmental Satellite (GOES-1), a dual geostationary operation began in 1975. By year's end, continuous day and night coverage was being provided from satellites near the equator at 75°W and 135°W longitude by the two-channel Visible and Infrared Spin Scan Radiometers (VISSR). Ample backup is now available since the launch of GOES-3 in May, 1978 for an operation which has continued without interruption over the past two and one-half years.

Apart from primary imaging sensors, the SMS/GOES operation provides for the acquisition of in situ observations through a Data Collection System (DCS).

Remote ground-based sites or ocean buoys are equipped with appropriate instrumentation and a Data Collection Platform Radio Set (DCPRS) through which data can be relayed to the central processing computers in Suitland, MD.

A scheduled rebroadcast of imagery and other weather information is also provided through the Weather Facsimile (WEFAX) service, starting first as a VHF service with ATS and now continuing as S-band transmissions from SMS/GOES.

1.2 NOAA Polar Orbiter Operations

Although earliest TIROS satellites were reconfigured in the mid 1960s to provide complete global coverage, the primary impetus for expanded operational applications came with the new day-night sensor packages on the Improved TIROS Operational Satellites (ITOS). NASA's prototype, ITOS-1, was launched in early 1970, and the last in the series, NOAA-5, was launched in July, 1976.

A two-channel Scanning Radiometer (SR) provides global coverage at 4 km resolution in the visible channel and 8 km coverage, both day and night, from the 10.5-12.5 μm infrared channel. 1 km imagery in a similar dual channel Very High Resolution Radiometer (VHRR) is provided in limited coverage -- either by on-board tape recordings from selected areas or through direct High Resolution Picture Transmissions (HRPT). Lower resolution SR imagery may also be acquired directly through the Automatic Picture Transmission (APT) service.

Atmospheric thermal structure information is supplied through a multi channel Vertical Temperature Profile Radiometer (VTPR), and these data are also available for direct user reception through a beacon channel rebroadcast service.

The ITOS series will have little or no impact on the planned future Aviation Weather System since a new polar orbiter series will soon be placed in operation. NASA's prototype, TIROS-N, is to be launched within the next few months, and with the launch of NOAA's first satellite in the new series, an early 1979 dual polar orbiter operation will have begun.

Present SR and VHRR imagers will be combined in an Advanced Very High Resolution Radiometer (AVHRR) in the new series, providing all-digital HRPT transmissions containing 1.1 km imagery in five spectral channels. A multi sensor TIROS Operational Vertical Sounder (TOVS) package will replace the VTPR. Its three components are the High Resolution Infrared Radiation Sounder (HIRS) for mid tropospheric detail, the stratospheric Sounding Unit (SSU) and the Microwave Sounding Unit (MSU) for better low level definition and cloud cover penetration.

Averaged imager data at 4 km resolution and TOVS information will also be retained on spacecraft tape recorders for global coverage.

A Data Collection and Platform Location System (DCPLS) is also included to provide data relay service and to measure motions of drifting platforms (buoys and floating balloons).

The dual system will involve sun synchronous satellites -- one with an 0730 southbound equator crossing and the other northbound at 1530 local time. The new system is described in detail in a recent NESS memorandum (Schwalb, 1978).

1.3 The Defense Meteorological Satellite Program (DMSP)

The DMSP Block 5 satellites have undergone significant upgrading modification since the early 1970s. The present Block 5D configuration includes an Operational Linescan System (OLS) with .6 km and 3 km imaging capability in both infrared and visible channels. A separate visible channel sensor provides similar resolution imagery at night with less than quarter moon illumination.

An atmospheric sounder package similar to VTPR is also included. Apart from data acquisition for central processing at the Air Force Global Weather Central (AFGWC), several direct readout sites acquire data for tactical users. The system consists of dual sun synchronous satellites -- one southbound in early morning, the other northbound near noon.

1.4 Experimental Operations with SEASAT-1

SEASAT-1 was launched on June 26, 1978, and, although experimental and oriented toward oceanography, operational processing of some of the data is planned as a demonstration project. Possible indirect contributions to flight operations might include factors which can dampen or augment thermal convective storm activity: atmospheric moisture content; rainfall detection; and soil moisture indications from Scanning Multifrequency Microwave Radiometer (SMMR) data; as well as weather developments in coastal areas as indicated by data from the SEASAT Scatterometer System (SASS) (See NOAA, 1977). While real operational dependence on such data may not be justified, indications of potential assistance from future operational microwave imaging systems might suggest some operational experimentation.

1.5. Recent Advances in Relating Satellite Data to Hazardous Flying Weather

Substantial strides have been made over the past several years in the application of satellite data to severe weather diagnosis and prognosis. Several investigations involve measures of cloud top temperature and time trends using GOES IR (Infrared) data. Although quantitative algorithms are used in treating

basic data, models which provide linkage to the pertinent weather event often invoke empirical assumptions, as, for example, in the estimation of convective rainfall. For this reason, some studies have applicability to hazardous flying weather, even though directed at some ancillary problem.

While most of these studies are applications oriented, there is some spread in terms of practicality of results for operational use. Separation into near-term and longer-term impact on flight operations support is undertaken in the following discussions.

2.0 NEAR TERM CAPABILITIES -- 1978-1980

In the near term, discussion of satellite products and services is confined to operational capabilities which already exist and to those items for which resources have already been committed and implementation is anticipated in the near future.

2.1 GOES

Those presently involved in obtaining GOES imagery for AWES are well acquainted with the so-called GOES-TAP landline distribution system and the product enhancement options and coverage constraints as detailed in the GOES/SMS User's Guide (1976). Current improvement efforts may be less well known. New emphasis is being directed toward removal of visible channel "striping" which arises through differential changes in the eight sensor photomultiplier outputs. Progress may result in more frequent changes in lookup tables which transform raw responses before the data are rebroadcast and disseminated. Steady progress is also being made in satellite navigation through more precise attitude and orbit maneuvers and with new, dedicated computer graphics equipment to validate image location through landmark checks. Engineering modifications are also underway which will permit a doubling of the volume of GOES-TAP transmissions without added landline capability. While other constraints remain, all of these efforts should enhance the utility of image products now being introduced into AWES.

Apart from GOES-TAP, much of the digital imagery enters the large-scale NOAA computer facility at Suitland for the extraction of a growing volume of quantitative observational products (Bristor, 1975). Some 1200M bytes of disk storage space are now dedicated to the central VISSR Data Base (VDB). New data ingest facilities will soon insure more immediate data receipt so that extracted products will be available well before source imagery is received by the GOES-TAP user. A centrally generated product of particular interest to AWES and now being readied for AFOS distribution is a cloud-top height analysis. Using cloud-top temperatures from the VISSR and temperature - height relationships from

the numerical prediction analyses, such height assignments are made for each 8 km picture element (pixel). Height trends are then deduced by monitoring such fields from image to image. In another effort, simple empirical relationships have been developed which relate the distribution and amount of showery rainfall to time integrations of cloud pattern responses in several temperature ranges and over an image sequence for a selectable time span. Although continuing developmental efforts are concentrating on rain patterns for landfalling hurricanes (Griffith et al., 1978), the approach appears valid for any convective shower regime.

Time compositing of GOES imagery eliminates transient clouds and permits broad-scale viewing of the underlying surface. Although the technique is particularly applicable to slowly changing ocean surface thermal pattern and pattern change monitoring, there is also application potential over land. If one saves only the coolest response for each geographic element which is repeatedly viewed during night time and the warmest during daylight, a maximum/minimum surface temperature chart can be generated. Since recent precipitation and high surface soil moisture strongly influence diurnal temperature changes, such satellite-derived charts have applicability in the projection of areas which will enhance or inhibit subsequent afternoon thermal convection. In their Chesapeake Bay nowcasting experiments, Scofield and Weiss (1977) stress the role of VISSR IR data in monitoring mesoscale temperature gradients in convective storm development, and one can project related consideration to the general case for AWES. Most of the current digital image product operations and experimentation at NESS are summarized in a recent paper by Waters (1978).

2.2 Polar Orbiters

Without constant surveillance capability for a given area, polar orbiting satellites cannot provide immediate support whenever adverse weather threatens flight operations, but higher resolution imagery and sounder data which they provide can substantially augment indications obtained from concurrent GOES data. The four looks per day from the TIROS-N series will provide 1.1-km imagery in IR as well as visible channels for such intercomparisons with 8-km VISSR IR.

The TOVS multi-sensor sounder package offers considerable support for CWSU operations. Data from 24 channels providing measurements from the surface to the upper stratosphere affords potential for several products beyond conventional soundings. These include temperature/humidity stability index charts, air route cross sections, and horizontal graphic array analyses involving various sensor channel combinations.

Similar capatilities exist in the case of the DMSP Block-5D satellites. Meyer (1976) has described the primary OLS (Operational Line Scan) imager, and recent request-for-proposal documents specify how other special sensors must interface with the on-board processor to blend their data with the imager bit stream. One such sensor is the SSM/T (Special Sensor, Microwave/Temperature) sounder package. Another is the SSM/I (Microwave Imager) for which a preliminary procurement request was recently issued.

Proceeding in parallel with satellite improvement, a major procurement is under way toward an upgraded satellite data handling facility at the AFGWC. Based upon an exhaustive Production Analysis Report (SAMSO, 1977), these new resources should greatly facilitate the timely extraction of satellite products for aviation weather. A primary product is the 3-D nephanalysis which provides cloud type, amount, and base-top altitudes in mesoscale boxes stacked 15 high and covering the entire global atmosphere. In the sounder area, the added microwave capability will provide the potential for aviation weather-related extractions similar to those mentioned for TIROS-N. Forthcoming updates to the DMSP User's Guide (1974) and the earlier nephanalysis paper by Coburn (1971) will provide needed insight toward future cooperative aviation weather information exchange possibilities.

3.0 MID-TERM ADVANCEMENTS IN CAPABILITIES -- 1981 - 1984

Although ongoing efforts to upgrade sensing and data handling tend to dampen near-term product development, the early eighties should see considerable progress in product extractions and user services in support of aviation weather. NOAA, like other agencies, is seeking to reduce manpower and expendable overhead costs through increased automation, and larger central computers are being considered for the early eighties (Balint, 1978). Within NESS, new dedicated computers and interactive display facilities will displace manual operations such as the present loop movie wind extraction activities.

Several CRT animation systems have been developed and two are in use by NESS. One at the WWB displays an 8-frame IR sequence in an automated update arrangement. Some 18 remote CRTs provide the animated display at the NWS forecast office and at operational work stations in NMC and within NESS. More interactive "soft copy" systems with animation and winds extraction capability exist in experimental facilities such as at the University of Wisconsin (Suomi, 1977) and at the Goddard Space Flight Center (Bracken, et al., 1977).

3.1 GOES Progress

Apart from processing power, the VISSR Atmospheric Sounder (VAS) will provide

further impetus for product expansion. VAS will first fly on GOES-D with launch projected for 1980. Its performance will be evaluated during prolonged experimental operations, and hardware/software preparations toward that end are presently underway at both NASA/GSFC and NOAA/NESS. In the normal operating mode, VAS will provide standard VISSR imagery plus selected sounder channel data. A detailed description of the 12-channel sounder and the several VAS operating modes has been provided by Montgomery and Endres (1977). Since experimental operations will focus on severe weather events, the success of VAS as an operational sensor could significantly affect input support to AWES. Frequent update imagery will provide close monitoring of rapidly developing storms through limited scan mode operations. Selection of appropriate auxilliary sounder channels in the VISSR mode will permit generation of atmospheric stability patterns on a continuous update basis. Operation in the sounder dwell mode will produce mesoscale sounding arrays at selectable frequent intervals so that short-term changes in atmospheric structure, such as have been documented by Wilson and Scoggins (1976), can now be monitored on a more continuous basis. The impact on AWES will thus be one of nearly continuous mesoscale inputs on severe weather developments and including periods of increasing threat before significant radar echoes or other direct indications are available.

Current NOAA/NESS budget requirements for FY-80 include support for a two-year continuation of VAS test operations. Projecting the demonstration of high utility during this prolonged test phase, one may speculate that an approved 3-GOES operation may commence by 1983. The third spacecraft, positioned at, say, 95°W, should be permanently dedicated to more frequent mesoscale data acquisition in order to optimize the monitoring of hurricanes, flash flood threats, and severe convective storm development. Although such a scenario is somewhat speculative, considerable thought has been given to such possibilities under NASA's STORMSAT studies (Hasler, 1976, and Lilly, 1977). If we assume a mid-eighties 3-GOES operation, a strong AWES interface arrangement would seem mandatory. In terms of basic imagery, such service might evolve from the beginning GOES-TAP operation. More frequent image transmissions might be handled by restricting coverage to areas with hazardous weather threat, and NESS line graphic or alphanumeric product messages might also be included in such a service. However, further automated manipulation at the CWSU would be hampered by such an analog dissemination system. Projecting continued advances in quantitative product extraction at both NESS and AFGWC, it appears that such inputs will grow in priority for AWES operations. But with increased update frequency and mesoscale detail, the effective use of these products will demand substantial communications bandwidth and high delivery

priority. A most appealing approach for direct, wide-band inputs of more voluminous derived products and basic satellite information for timely application at each CWSU involves the direct local antenna acquisiton approach. Tests by Larranaga (1978) suggest acquisition systems far simpler and less costly than those presently used for direct GOES data access. A recent news item presents the Associated Press as a bellwether in this area (Electronic News, July 3, 1978). Current tests involving 25 small-antenna earth stations are aimed at the replacement of an AT&T Long Lines network with some 500 to 700 direct access stations interfacing to signals relayed by a communications satellite. With operational installations scheduled directly after the 6-month test period, AP apparently sees space communications as a cost-effective near term solution. With lowering lease costs for communications satellites transponder channels, a related suggestion is currently being made for an expanded digital GOES WEFAX service (Bristor, 1978). A 60K bps retransmission system using such a communications satellite is proposed whereby basic imagery or derived products could be distributed to individual low cost ground acquisition sites. Hopefully, one may look toward affordable direct acquisition facilities for more widespread local applications, such as at ARTCCs, within the next few years.

3.2 Advances in Polar Orbiters

Early TIROS-N AVHRR imagers will contain only four sensing channels -- the 3.7-um and 11.0-um IR channels to be used for removal of partial cloud cover ambiguity in measuring surface temperature. Later models will include an additional IR channel to permit correction for variable atmospheric water vapor. Apart from this change, the system provides for some 20% growth in payload, but projected additional sensors will have little direct impact on AWES. Without constant surveillance, polar orbiting imagery and soundings will have continuing importance in aviation weather mainly as inputs to prediction models. Whereas present dynamic models rely primarily upon rawindsonde data, the TOVS data will provide more dense soundings four times per day. Adding this information to mesoscale wind arrays and soundings obtained from VAS, satellite inputs will provide impetus for more frequent, short-term model predictions.

As for product availability, current NESS preparations will soon lead to marked improvement over present ITOS arrangements. The recently installed Ampex Terabit Memory (TBM) system will contain all basic polar orbiter data and products acquired and generated over an entire 24-hour period, and these will be available on-line for near real-time use. A currently funded Environmental Satellite Data Access Study (ESDAS) is addressing alternative strategies for maximizing the availability

of such data and products for the broader user base. Through simulation modeling of alternatives, including formats, interfacing procedures, and a hierarchy of options (spatial resolution, observation time, geographic coverage, sensor channel, production and delivery priorities), means are being considered to best serve clients ranging from those wishing a simple Teletype-relayed transmission once or twice per day to a larger scale user with voluminous data requirements. Although interfacing considerations are involved, the study does not address the communications media aspect, and these must be addressed with user-provided resources. Study details are available in a final ESDAS contract report (1978).

Projecting DMSP progress, by about 1982, the mentioned new data acquisition and processing facilities at AFGWC will have stabilized. Diverted software resources will again be available for applications development, and adequate hardware manipulating capacity will be available for new product testing. As for new sensor inputs, the mentioned microwave imager and sounder data, together with contractor-supplied product processing algorithms will all have been assimilated into the operation. If one projects current study efforts, more detailed information on cloud structure will then be added to the 3-D Neph (Feddes and Liou, 1978), and new sounder channels will ease the present burden of extracting atmospheric thermal structure in the presence of clouds (see earlier effort by Nagle, 1977). By 1984 an expanded Block-5D product mix will likely have reached a mature, operational status. With overlapping aviation weather interest, option should therefore be retained to consider AWES acquisition of data and products from AFGWC.

4.0 LONGER TERM PROJECTIONS: 1985 - 1990

Although the impact of satellites on aviation weather operations for the late eighties must be more speculative, considerable planning effort has already been invested toward a new geostationary/polar operational weather satellite system. A fresh look is being given to all aspects -- the interplay of polar and geostationary sensing to optimally meet expanding requirements, and the data handling and product services needs to maximize user impact. With the trend toward remote sensing in more spectral channels at higher space and time resolutions, (Nagler, 1977) it would seem inevitable that increasing support will be available for AWES. While this effort has not progressed sufficiently to influence current aviation weather planning, Appendix A provides further background for future consideration.

5.0 AWES SATELLITE INFORMATION ACCESS CONSIDERATIONS

All of the foregoing discussion is intended as an overview of the operational weather satellite program -- what it is and what it can provide in the near term,

and what the future is likely to bring. Although directed at aviation weather service needs, the discussion, thus far, makes no direct recommendations as to how AWES should further develop its utilization of weather satellite information. As one lead into such recommendations, this section deals with satellite information access alternatives and assumes a stage in the development of AWES at which all ARTCCs will have access to Laserfax satellite imagery via GOES-TAP and with no other satellite inputs beyond the marginal quality imagery available on weather facsimile circuits. As this point is reached, and with other appropriate CWSU facilities and personnel in place, the question is addressed: What are the next steps to maximize the impact of operational weather satellites on AWES? According to present schedules, GOES-TAP installation at all ARTCCs and at ten selected FSS sites should be completed and all CWSUs should be fully manned and activated by late 1979. Allowing for a needed period for operational stablization, one might select mid-1980 as a likely point at which further upgrading alterations might be considered. Information access considerations are therefore discussed in this time context.

5.1 Satellite Inputs from AFOS

The operational testing of AFOS on a limited network basis has increased pressures for digital satellite products, and, in recent weeks, additional experimental image products have been declared fully operational. These will augment sea-surface temperature, cloud motion winds, and other present alphanumeric telecommunication message products which will also be included on AFOS. If one considers current NESS product development efforts, products now in experimental test status, and others already developed and on standby, it is evident that satellite information will represent a significant portion of the AFOS data base. Table 5-1 projects the likely satellite product mix available for AFOS consideration by mid-1980. Not all listed items are relevant to the AWES mission. Those of interest may not be distributed because of priority, or they may not be available in optimal format for aviation weather applications. Clearly, there will be bandwidth constraints which will preclude timely distribution of voluminous products and basic imagery. But, considering other AFOS offerings -- basic weather data, mesoscale (dynamical and statistical) prediction model outputs, and advisory material from the National Severe Storm Forecast Center (NSSFC) -- there is little doubt that AFOS will play a vital role in CWSU activities. AFOS will likely require 3-5 years in order to reach maturity. If, by that time, band width much beyond the planned National Distribution Circuit (NDC) is not available, other transfer channels will be required for optimal impact of satellite inputs to AWES.

Table 5-1. Estimated NESS Products Status in Mid-1980. "0" indicates operational; "D" developmental; and "A", available for distribution within the central data base.

Item	Status	Basic Data Utilized
Cloud Type/Amount	0	Hourly VISSR IR plus available visible channel
Cloud Height	0	Periodic (3-hourly) VISSR IR plus NWP history files
Cloud Height/Change Analysis	A	Half-hourly VISSR IR
Area Precipitation Estimate	0	Three-hourly VISSR IR
U.S. Quantitative Precipitation	A	Half-hourly dual channel VISSR
Flash Flood Monitor	A	Half-hourly dual channel VISSR
Winds Synoptic Scale	0	Periodic half-hourly clusters plus pairs of dual channel VISSR
U.S. Meso Wind Fields	A	VAS/VISSR limited scan image sequences
Soundings	0	Four-per-day TOVS, six or eight-per-day VISSR/VAS
Stability Analyses	A	Four-per-day AVHRR/TOVS, six-per-day VISSR/VAS
Insolation Estimates	A	Hourly daytime VISSR visible channel
Freeze Event Monitoring	0	Hourly VISSR IR, mainly night time
U.S. Diurnal Surface Temperature Change	A	Hourly VISSR IR plus VAS mode moisture channels
Sea Surface Temperature; Synoptic Scale	0	Four-per-day AVHRR plus TOVS moisture
Meso Sea Surface Temperature: Coastal Areas	0	Half-hourly VISSR dual channel clusters plus AVHRR
Hurricane Intensity/Movement	A	VISSR IR at frequent intervals
Soil Moisture Estimates	D	Hourly VISSR IR plus VAS moisture channels
Fire Danger Index	A	Hourly VISSR IR plus VAS moisture channels
Snow Cover/Amount Chart	0	Four-per-day AVHRR

Item	Status	Basic Data Utilized
Great Lakes and Coastal Ice Charts	0	Four-per-day AVHRR
Global Severe Weather Alert Messages	0	All available AVHRR/TOVS plus VISSR/VAS
Combined RADAP/VISSR Trend Analysis	D	All VISSR and Radar inputs

5.2 Possible Need for Direct NESS/NMC Data Base Link

Apart from bandwidth constraints, there may be other information, unique to the nowcasting needs of aviation weather, which resides in the Suitland data base, either as basic data or as an extractable product not otherwise distributed. One example could be aircraft weather reports which are obtained via DCS through the Aircraft Satellite Data Relay (ASDAR) system (see NMC, 1977).

Although arrangements provide relay of such reports through NESS to NMC and then into the AFOS system, more direct access may be desirable to assure priority receipt of all reports, not edited summaries. Another possible information source is the complete history file produced by fine mesh mesoscale, short-term prediction model integrations. Since the CWSU duty forecaster must weigh and update such model predictions, his effectiveness could be greatly enhanced if outputs were expressed directly in terms of cloud cover and hazardous weather events which he is monitoring. Although contained in the predictions, such interpretive model outputs, at frequent intervals, are not presently produced for distribution.

In the case of basic satellite data, one may also consider specialized products. Using VISSR IR data, one may track cloud top temperatures and automatically indicate threatening cell-cluster developments before radar echoes develop (Adler and Fenn, 1977). And using upper-tropospheric or stratospheric sounder channels, one may generate isobaric thickness patterns indicating the position and intensity of jet stream features at finer scale resolution than can be revealed by NMC grid-point analyses. Previously mentioned vertical stability analyses may also be produced in a variety of special forms for operational testing and evaluation.

Even if limited to the relay of low-volume specialized data or derived products, such linkage, separate from NDC, may well prove worthwhile. If message content could become highly standardized and total bit bulk delimited, one might schedule inclusion of such information on NADIN. Unfortunately, the optimum use of specialized material tends to involve many options including selection of the area of interest, and frequency and type of information required, depending upon the degree and kind of hazardous weather threat. A better way to meet this need is through an interactive, direct-access terminal such as now provided by the NOAA central computer Time Sharing Operation (TSO). Using central computer software, remote users may gain access and obtain specialized products under

user-selectable options. With each of the three 360/195s undergoing main memory expansion to 3M bytes, it appears that present limited TSO service to some 35 terminals will soon expand to a full 24-hour, 7-day service for some 50 remote user terminals. With further computer augmentation planned for the early 1980s such service could expand to limited non-NOAA users. Serious consideration of such an option would, of course, involve negotiation, not only for access, but for specialized applications software.

5.3 Direct GOES Satellite Access

Several direct access possibilities exist, but the most appealing local antenna approach deserves some amplification. If such local facilities -- antenna, downconverter, receiver, demodulator -- are to be considered for each ARTCC (and perhaps some FSSs), assurance is needed that superior, trouble-free, and cost-effective service will result. Beyond interest within commercial circles (e.g., the Associated Press procurement), government-funded efforts are being directed at such broadening of satellite acquisition applications. A recent news item (Telecommunications, June, 1978) reports on a NASA/GSFC contract aimed at developing mass-producible receiver and low-noise amplifier components to be used with a 1-meter dish antenna for multi-gigahertz reception. The announced ultimate goal is a complete television terminal installation for under $1,000. With similar capability for low-bandwidth geostationary weather satellite data rebroadcasts, one could project great flexibility in direct inputs to the AWES. Since fixed position, broad beam antenna, and data acquisition under microcomputer control implies minimum human supervision, products could enter the local data base with operations as stable as one might expect using lower-bandwidth land lines.

With substantial advances in ground systems likely by 1982, direct access facilities could interface with several possible geostationary satellite signals. The mentioned narrow-band WEFAX service presents simplest interfacing requirements, and, as the service matures, a diverse mix of imagery, line graphics, and alphanumeric products will be available. However, unless mission goals change, WEFAX will not provide half-hourly imagery and, consequently, will not replace the GOES-TAP service. At the other extreme, one might acquire the full-stretched VISSR/VAS transmission, thus obtaining the digital source data from which GOES-TAP signals now originate. This would provide ultimate local flexibility to acquire data for selectable sensor channels, with complete freedom to apply any desirable enhancement, and for times and places optimized in support of local weather missions. Under half-hourly full-earth disk imaging operations,

the computer-managed acquisition procedure would discard all unwanted coverage. In the limited scan mode, discarded material would be minimized since the primary target area would include sections with hazardous flying weather. If slower hardware developments preclude such automated acquisition of the full 1.2M bps signal within acceptable bit error rates, then the mentioned intermediate digital rebroadcast service might evolve. With positive developments under way, an optimum approach would seem evident by the time present GOES-TAP/CWSU installations have been completed and operations stabilized.

Also to be noted in satellite interfacing is the important Inovative Video Applications in Meteorology (IVAMS) effort (1978) at the University of Wisconsin. That effort toward "a computer-based semi-automated information processing system to support a nowcasting service" dealt mainly with manipulating imagery for optimized graphic presentation, but input to this digital system did consider interfacing to the GOES-TAP landline signal. The effort included design of an improved input data module to: process the redigitized input image at transmitted and reduced resolutions; provide continuous automatic gain control; and to improve frame/line synchronization. While this approach could provide a graceful transition from Laserfax to a more flexible image manipulating capability, the reduced quality input signal would remain restricted to the scheduled sector and sensor channel selections and to the enhancement table chosen at the distribution point. High interest continues at NOAA/NESS in an eventual replacement of the GOES-TAP landline service with direct digital access at its several field service stations, and perhaps by 1982, such change will be under way.

6. SATELLITE INFORMATION MANIPULATION FOR MAXIMUM AWES IMPACT

Recent interagency agreements identify CWSU facilities to be provided by the FAA, and additional background material provided by the NWS Aviation Branch describes the duties and responsibilities of assigned personnel. Projecting this configuration into the previously described satellite environment of the early eighties, one can foresee pressures for augmentation. Diverse masses of basic satellite data and many derived products will potentially be available to the flight service meteorologist who could then be required to assimilate their indications, both for strategic short-range foreceasts supporting flight operations planning, and for immediate nowcasting in support of inflight avoidance of hazardous weather. There would also be a need to amalgamate these findings with weather radar and other conventional weather indicators. The following discussions amplify the possible role of augmented satellite inputs

for both short-range and nowcasting missions.

6.1 Strategic Weather Support

Several NOAA operating units -- NMC's Aviation Branch, NSSFC, NHC, and the NESS Field Service Stations -- now provide routine inputs in support of flight planning operations. While such inputs are updated periodically (mainly on a 6-hourly basis), flight operations planning is, perforce, a continuous process. The challenge therefore would seem to involve means to incorporate GOES imagery more directly in a continuing update mode. Even though statellite inputs are now used in the periodic update process, it would seem much more desirable if 0-6 hour advisory projections could be made available on an hourly or even half-hourly update basis for use in the Central Flow Control Facility and in the ARTCCs. This would likely involve more resource commitment if carried out within the several NOAA issuing units, and would still not result in a single flight advisory product. With continuous satellite imagery as a prime tool, this integration task might better be made the responsibility of the AWES.

However the need for improved support to flight operations is resolved, there should be a more complete amalgamation of all inputs. Ideally, one might view this as a multi-data source algorithm, accepting fine mesh dynamic model and statistical model projections along with all basic observational information, and, using maximum likelihood estimator logic, to generate outputs specifically tailored to the needs of flight planning operations. Clearly, the complete assimilation of the growing volume of finer-scale inputs will require substantial automation, but human interaction will be needed to provide judgemental override for still imperfect solutions. The trend in predictive outputs from such a continuously updated algorithm would tend to have strong appeal. Oscillations around validating conditions would be more gradual and without surprises possible in present 6-hourly updates. Once such short-term projections of significant weather became available on a constantly updated basis, both graphic and voice output formats could be devised for optimum use. These would be incorporated in a hierarchy of user interface applications including pilot self briefing (as mentioned by Roche and Glassburn, 1976, and by Lindquist, 1977). While implementation of this kind of ultimate system would likely require major software investments, the concept may have value in planning future AWES augmentation. Some related evolutionary development ideas are presented in Section 7.

6.2 Nowcasting Support

Those directing and providing weather advice for enroute flight operations, for years, have been engaging in 0-30 minute nowcasting activities using simple persistence and subjective extrapolation as predictive estimators. The immediate response requirement for such continuing service is stressed in present planning for improved AWES. Image enhancement and any other manipulative treatment of supporting satellite inputs must be, essentially, an on-line process. In particular, if limited scan VISSR/VAS inputs are provided at 3-/or 5-minute intervals, any processing delay should be reduced to seconds. However, this does not mean that such treatments are impractical. With modern computer support locally available, several manipulations may be considered which would significantly increase the utility of GOES imagery over hard copy photo prints.

Animated CRT display of VISSR data is one treatment which should receive priority consideration. While few objective statements are to be found in the literature, users with access to single photo prints and the corresponding animated sequence display, invariably concede the great superiority of the latter. Some of the more prominent advantages of animation are listed in Table 6-1. Although loop movie production still predominates within NESS operations, the trend is toward CRT animation which has been developed in the McIDAS (Man-computer Interactive Display and Analysis System) at the University of Wisconsin and in the AOIPS (Atmospheric - Oceanographic Information Processing System) at NASA/GSFC. A related Television Picture Terminal (TPT) facility at NESS displays an 8-frame selectively enhanced sequence at some 18 CRT monitor stations in various operational work areas throughout the WWB. In the TPT, the most recent image, as it arrives, replaces the oldest without delay. An effort currently funded by the National Weather Service is aimed at developing a more advanced but lower cost equivalent system for widespread use at field stations. Such facilities should also be considered as an early 1980s first step beyond Laserfax hard copy for AWES.

A flexible all-digital animation system can also be used for display of radar data and for graphic analyses from fine-mesh numerical prediction models. An experimental NESS Image Analyzer device at the NESS/SFSS, Kansas City, provides dual display for simultaneous viewing both visible and IR imagery from GOES. A system with such feature could provide either juxtaposition of superposition capabilities for any graphic material, and so supply vital nowcasting assistance in the intercomparison of various trend indicators.

Table 6-1. Advantages of Animation over Static Scene Viewing

1. Elements in multi-layer cloud patterns are better identified and separated by their relative motions, thus revealing upper- and lower-level circulation patterns and providing insight into strong shear regimes.

2. Elements belonging to the same circulation mechanism can be readily identified as in the case of convective cells sometimes widely and unevenly dispersed along a gust front.

3. Stagnant fog and fields of low stratus are more readily separated from transient cloud fields by their obvious stationarity.

4. Cloud systems undergoing significant growth or deformation are rendered more noticeable.

5. Jet stream cirrus with tenuous edge features are more readily detected as they traverse varying cloud/surface backgrounds.

6. Cloud pattern displacement trends are far more obvious whether moving with the general flow, as in the case of a squall line system, or where upstream convective activity is producing retrogressive development.

Other valuable treatments include time compositing which permits more automated intercomparisons of pertinent image features in a constantly updated mode. For example, means could be developed, based upon related past experiences, to automatically monitor cooling trends in convective cloud tops using VISSR IR data. Following a current study by Adler and Fenn (1978), one may thereby obtain a continuous update on the relative intensity of thunderstorm regimes. In another compositing application, one might obtain objective measures of the rate of ground fog dispersal by maintaining a running count of the number of pixels in a local area whose brightness response is above some selected level.

Experience gained with a flexible image manipulating facility will, no doubt, lead to other treatments such as blink intercomparisons between inferred cloud fields predicted by mesoscale models and actual GOES imagery. Also to be considered is the ability to march through the brightness or thermal topography of an image, displaying, in a black/white graphic mode, all pixels above and below the changing threshold. These or other application developments would serve to rapidly review weather details in briefing meteorologists, controllers and EFAS personnel -- particularly at shift changes.

7. FUNCTIONAL REQUIREMENTS FOR HARDWARE/SOFTWARE FACILITIES

The present purpose is not to provide specifications but to describe hardware and software needs in terms of suggested functional requirements. In the software area, the developing AFOS system has much to offer in interactive system design and applications modules (Merritt, 1977), and the previously-mentioned AOIPS and McIDAS systems provide a background of experience in image data manipulation. But, despite efforts in both areas, much remains to be done before a truly input-integrated, operational nowcasting facility is produced.

7.1 An Animated Display Service

Animation capabilities vary between developing systems depending upon differing requirements. The newly-installed interactive system at Colorado State University contains sufficient 8-bit pixel storage for an 8-frame sequence in a 512 x 512 element display. The forthcoming NES system will be required to display half-hourly imagery in 48-frame sequences for a full day's coverage. If one projects 5-minute imaging intervals in future GOES nowcasting support, a 24-image, two-hour display capability would appear to be a reasonable compromise. Apart from storage bulk, each application tends to have other constraints in requirements such as the ability to quickly alter enhancements, shift to zoom mode, or other option. With the stress on multi-source information blending diversity and quick-response nowcasting support as prime

considerations, one may select attributes optimized for such application, and a suggested list is presented in Table 7-1.

7.2 Source Data Access and Preprocessing

With multi-source inputs, a centralized nowcasting facility must establish format and access procedure standards in order that utility software modules have widest applicability. Information arriving via NDC will enter in the format prescribed by the Advanced Digital Communications Control Procedure (ADCCP). AFOS will provide preprocessed radar information from RADAP as well as several relevant satellite-derived products. But more basic data sets and other products available from NMC and NESS may be available in different formats and through other channels. If the AFOS data base management system permits graceful augmentation and handling of such additional kinds of information, then that system could perhaps serve as the standard. Once the standard is selected, most incoming signals can be reformatted upon arrival using serial microprocessor techniques, the so-called "smart wire" approach.

As for source data preprocessing, much raw data bulk is normally eliminated as interpretive products are extracted at the source. The NES Digital Radar Experiment (D/RADEX) suggests nine such products for likely activation under the RADAP program (NOAA, 1977). However, satellite imagery tends to cover a wider digital response range with more diverse applications potential ranging from cold cloud-top monitoring to changes in surface heating. Unless reduced extractions can be produced for all pertinent aviation weather applications, there will be need for basic data -- at least for the local region of operational responsibility. With raw GOES data already reduced through radiometric correction and annotated for geometric normalization, remaining preprocessing will include diagnostic quality assurance, sectorizing, and data base entry. In order to maintain long-term flexibility, a separate acquisition and preprocessing computer facility appears desirable as in other systems. Further preprocessing and display functions are thereby isolated and need deal only with the on-line data base.

7.3 Product Processing and Manipulative Support

A recent report (Anthony and Bristor, 1977) discusses in some detail the software needed for an interactive nowcasting system. Many of these routines already exist in FORTRAN as part of the AOIPS software package (see the METPAK report to NASA by Computer Sciences Corporation: Billingsley et al., 1977) or

Table 7-1. Suggested Animated Display Capabilities.

1. Ability to display 24-frame image sequences in at least 16 gray shades or color levels (4-bit pixels) using quickly reloadable solid state refresh storage.
2. Option to reconfigure refresh storage to provide 12-frame sequences using 8-bit pixels for maximum response range display, or to produce longer sequences with fewer bits per pixel, including 96-frame, black/white, single bit graphic sequences.
3. Ability in color display mode to intermix and blend three different source signals.
4. Capability to alter frame repeat cycles on an individual basis to create pauses at sequence extremities or produce other timing patterns.
5. Ability to establish a blink alternation using any selected image pair from the refresh storage and with adjustable timing rate. This would permit intercomparison between weather radar and satellite image pairs or other combinations.
6. Provision for remote display drops.
7. Trackball or tablet interface for interactive coordinate identification.
8. Adequate interface computer support with ready access to all required source data to minimize delays for display changes.

as part of the McIDAS system (Suomi, 1977). Tasks requiring greatest hardware/software resources are those performing algorithmic reduction of basic data. For those cases where unique extractions of high value to aviation weather nowcasting are not carried out elsewhere, substantial midi-computer power (Theis, 1977) may be required. Examples might include the mentioned reduction of multi-channel VAS data to produce atmospheric stability arrays or specialized cross sections for specific air routes, and perhaps also include time compositing to monitor cloud top temperatures. Pattern extrapolation algorithms present yet another substantial data manipulating task. Several groups have devised programs which project weather radar echo patterns for short periods. Elvander (1976) has compared several such algorithms, and finds that one of the simpler approaches has skill comparable with a more complex approach requiring more computation. All have skill well beyond persistence, and it would seem that such a generalized routine would be desirable for both radar and satellite cloud pattern projections.

Other software capability can be grouped mainly under interactive and graphic display support. Routines such as those which produce isoline patterns from digital messages on AFOS would be included along with data plotting and labelling subroutines. Other image array manipulators are needed to perform x, y shifting, zoom/reduce, spatial operator enhancement, and extraction of summary "events" of interest to the aviation weather mission. Cross correlation and vector end-point displacement calculation routines, such as are used in cloud motion wind estimation, may also be useful.

One group of utility routines is needed to sector select, format, and load data base information into refresh storage for animated display. Other routines would provide blending or juxtaposing of multi-source inputs. Because of the different perspective of satellite imagery, replotting of all inputs to a standard geometric base may require substantial resources. All mission functions require the support of a large data base system with ample on-line storage. At present, low-cost disks in the 20-30M byte range and in multiple units appear to be a likely solution.

The assimilation of all inputs into a unified operational nowcasting facility could be based upon a dual computer AFOS facility with radar and satellite image handling augmentations, or one might consider a McIDAS-like system with AFOS features added. By the early eighties, the availability of more powerful, low-cost computers may suggest a third approach centered on the specific needs of AWES and incorporating optimum hardware capabilities and adapting only pertinent software from the other systems. Whatever the approach, considerable additional

software development will be needed to produce a quick response, dependable operational system which will activate capabilities now demonstrable in limited combinations, and in non time-critical developmental modes.

8. SUMMARY AND RECOMMENDATIONS

With weather satellite inputs as the focus, this study has considered many factors which bear upon plans for an upgraded FAA Aviation Weather System, and these are recapitulated as a summary outline in Table 8-1. Because of the many meteorological and engineering aspects, an aviation weather system with optimized satellite data utilization represents a complex developmental effort. Even with contract support, such an effort requires appropriate expertise within the FAA's Systems Research and Development Service. In the flight information services area, one might disperse developmental task responsibilities to automation engineering, weather techniques, systems analysis and other areas of skill, but this would be ineffective without guidance from a unit charged with overall responsibility for the satellite applications development program.

It is therefore recommended that an organizational unit be established with singular responsibility in the satellite program area. The expert leader of this effort would monitor the various operational satellite programs, and, through the establishment of a Center of Understanding, guide the developmental effort. On the basis of such an organizational focal point and considering the topics summarized in the table, the following additional recommendations are made as a contribution to the AWES Preliminary Program Plan.

8.1 Animation in Support of Strategic Aviation Weather Forecasting

GOES information is unique in that it provides constant evidence of the results of atmospheric circulation developments. Ground fog, low stratus, dust, varying surface thermal patterns, cirrus signatures of jet streams, and convective storm developments are all observed, and the trend toward more frequent remote observations along with finer resolution in more sensor channels points toward a continuing enhancement of such information. As other inputs also increase in frequency and volume -- from radars, prediction models and from an expanding variety of in situ measurements -- the aviation weather forecaster is threatened with an overwhelming assimilation task. In 2-6 hour strategic planning for air operations, his contribution should be based on all evidence available, including possible conflicting indicators. Using animation as a key tool, the forecaster's assimilation tasks could be considerably eased. By an optimized structuring of concurrent indicators, through superposed and/or juxtaposed displays, he can make comparisons on a continuous basis. Animation of cloud field

Table 8-1. A Projection Summary of Likely Developments

1. Technology Developments

   a. Bandwidth enhancing improvements in digital microwave data communications from satellites permitting dependable, low cost, direct access ground acquisition installations.

   b. Increasing computer power in less bulky, more easily maintained configurations at low cost.

   c. Expanding data storage capabilities for very large, on-line data bases with much faster input/output transfer rates.

   d. Specialized but highly programmable array processors for rapid reduction of massive quantities of image data.

2. Weather Satellites

   a. Expansion in number of indirect sensing channels including both active and passive microwave sensing.

   b. Improvements in imaging spatial resolution including footpad size of 1km or better from geostationary altitude.

   c. Basic sensing improvements in terms of response range, sensitivity and calibration.

   d. Improved on-board, ground reprogrammable data processing.

   e. Improved navigation and earth location of data.

   f. More frequent global sensing with prompt data relay.

   g. Improvements in extracted products and information dissemination.

3. Weather Data Applications Developments

   a. Progress in finer mesh dynamic prediction models and in statistical models with greater use of satellite inputs.

   b. Progress in applications of direct satellite inputs in severe weather nowcasting.

   c. Improvements in information blending.

   d. Progress in establishing operational digital extraction products from radar (Doppler) and satellite data.

representations extracted from short-time-step meso-scale numerical models can thereby be directly compared with validating satellite cloud animations, and erroneous departures of model predictions quickly discerned.

Independently produced terminal and route forecasts can also be monitored for early period validation as newer satellite imagery is received. Severe weather depictions produced at NSSFC or by central statistical models may be compared with validating imagery using the image pair blink technique, and jet stream configurations on prognostic charts can similarly be compared with validating patterns obtained from animated cirrus cloud regimes. With animation as the primary assimilating tool, the forecaster can more reliably adjust the weights given to all available indicators and so improve his contribution to flight planning. It is therefore strongly recommended that, in each CWSU, a diversified animation capability be considered as the next step beyond Laserfax hardcopy.

8.2 Animated Nowcasting Support

Some of the animation support for strategic aviation weather predictions also applies to the 0-30 minute nowcasting task, but, as important hazards to flight operations become imminent, other important needs for animation arise. Subjective, very short term projections of current trends in convective storms, ground fog and other transitory events can be quickly made and passed to controller and EFAS personnel. With proper computer support, previously mentioned objective extrapolations can also be produced and displayed in animated form. Intercomparisons between satellite image sequences and weather radar echo sequences can also deepen nowcaster insight. In the case of progressive severe weather outbreaks, the two kinds of imagery can be complementary. The temporal and spatial rhythm in such cyclic outbreaks, as revealed by the combined imagery, may focus on the next likely outbreak point as revealed by satellite cloud imagery before new echoes occur. In such application, the mentioned geometric normalization problem becomes very important. If compressed radar messages are obtained promptly via AFOS, the present McIDAS approach, projecting such low-volume information into the satellite image perspective, may be the most economical solution. But, if more voluminous local radar data is available, one may wish to intercompare more detailed pattern features. Ideally, one would wish to see all source data remapped to an agreed standard format. Whatever the solution, animation activities in support of nowcasting requires substantial midi-computer support, and such need is therefore presented as a major recommendation.

8.3 Cooperative Support from NESS

Much applications development is needed to assure optimum extraction of remote observational products from basic satellite data, and a cooperative effort is urged to assure proper emphasis in extracting those input items which would enhance the aviation weather service. It is recommended that specific product requirements be presented to NESS and that a cooperative resource commitment be made to assure optimum product development with prompt arrangements.

NESS is achieving increasing precision in satellite navigation, but user interest might enhance resource commitment in this area. In the European Space Agency's (ESA) operation of their geostationary Metorological Satellite (METEOSAT), geometric image normalization is accomplished centrally so that users with direct access obtain imagery with the earth disk central pixel always positioned on the equator at the Greenwich Meridian. A fixed pixel-to-latitude/longitude coordinate relationship is thereby created. Inclusion of such normalization has been suggested to NESS but no action is currently planned. It is recommended that interest in this problem be stated in connection with the needs of the aviation weather service and that preference be stated toward an effective solution.

Both internal and external proposals have also been presented to NESS management for the further development of low cost, digital, direct access satellite ground systems. The related activity mentioned earlier emphasizes the timeliness of these suggestions, and it is therefore recommended that the FAA encourage such development -- either with direct participation or with resource commitments.

8.4 Coordination with Related Interactive Display Developments

Many interactive weather satellite facilities are being developed with features pertinent to the aviation weather service, and FAA interests will be well served by continuing cognizance of the following programs:

1. AOIPS, described by Bracken et al. (1977), continues to develop with additional applications software investments and additional computing power scheduled for VAS data handling.
2. The McIDAS facility similarly continues to expand functionally with direct contributions from a NESS meso-meteorology applications development team. Several advanced McIDAS-II configurations are being produced

for deployment in support of experimental VAS operations.

3. At NESS, several early Man-Machine Interactive Processing Systems (MMIPS) have recently been supplemented by two McIDAS systems (called VIRGS -- Visible-Infrared Gridding System) with early use centered on landmark navigation functions.

4. The Air Force Geophysics Laboratory has deployed a flexible color display system in support of recent operational tests of Doppler radar in Oklahoma, and there are features of interest also for satellite imagery display. An interactive display system for satellite imagery will be a part of the new ground system procurement for AFGWC.

5. The Naval Weather Service development of NEDS (Naval Environmental Display System) has recently been followed by the related development of SEIDS (Satellite Environmental Interactive Display System).

6. The mentioned effort at Colorado State University is patterned after McIDAS, but with large solid state display refresh storage.

7. At NESS, one should also include the mentioned TPT and a related Image Analyzer device, capable of dual-channel animated display, and now in use at the field station collocated with NSSFC.

8. NWS is soon to release a request for the development of new, low cost animation devices for use at AFOS field sites. This coming development is based, in part, on experiences with a prototype VSDS (Video Satellite Display System) which has been used in conjunction with AFOS test facilities.

With varying mission emphasis, all of these efforts have addressed design problems relevant to aviation weather needs, and it is recommended that AWES planning include a continuing monitoring of these developing systems.

8.5 Related Weather Interface Develcpments

With VAS, there will be marked improvement in the quantity and frequency of meso-scale data, and this will provide an impetus for further development of fine-scale dynamic prediction models and for the more frequent rerunning of such predictions. It is recommended that AWES interests be emphasized in these developments and in the potentially expanding operations with particular emphasis on configuration of outputs for maximum impact on the aviation weather mission.

In the development of short-term statistical predictions, the FAA has provided substantial support to the NWS Techniques Development Laboratory (TDL) (e.g., Charba, 1977), but, thus far, little consideration has been given to the inclusion of satellite data. With expanding offerings, it is recommended that such continuing support in developing new non-linear statistical models include consideration of satellite inputs.

The stresses generating need for an improved aviation weather service (Bromley, 1977) are occurring at a most interesting stage in the development of remote sensing and related data handling technology. With proper planning, hopefully enhanced by this study, one may see evolving systems with a major contribution from weather satellites.

APPENDIX A. PLANNING NEW WEATHER SATELLITES FOR THE LATE EIGHTIES

Planning efforts for the new "System 85" are proceeding with consideration of all pertinent state-of-the-art developments. Participants from NASA/GSFC and from NOAA/NESS will produce a requirements/definitions background document by late 1979. After a preliminary period with comments and suggestions from industry, more detailed contract studies will be funded toward final system specification. Hardware/software "build" contracts will likely be issued in 1982 with first launches perhaps by 1985. Based upon present sensor development efforts and requirements-expanding applications studies, one can discuss possible configurations.

A.1 The New Geostationary Series

The more obvious requirements for a new system are those which remove constraints in present operations. In the case of GOES, limited scan mode operations in support of severe storm monitoring has presented conflicts with cloud motion wind extractions and with other operations which require full earth disk imagery. And the coming VAS operation will present additional operating mode conflicts -- in the imaging mode because of differing user desires for auxiliary channel selections, and in differing demands for alternation between imaging and sounding mode operations. Other new requirements involve improved sensing capabilities where demands for greater stability, wider dynamic range, and greater spatial resolution have always closely followed the state-of-the-art in sensor developments. Although much work remains in consolidating requirements, some of the more likely candidates for the new system are listed in Table A-1.

A.2 New Polar Orbiters

As in the geostationary case, new requirements first tend to address present operational constraints. The most serious problem with polar orbiters has been tape recorders. The bulk of data acquired over remote areas has been severely limited and data losses have occurred as tape dumping conflicts arise with new data acquisition, and significant delays are suffered between data acquisition by the spacecraft and availability of outputs to the user. Since NASA's developing Tracking and Data Relay Satellite System (TDRSS) offers means for direct, continuous data acquisition from polar orbiters, such relay capability will, no doubt, appear as a primary requirement in the new system. Beyond the sensor-related needs mentioned in the geostationary case, new sensing demands also arise when technological breakthroughs provide the means to implement space-borne equivalents of already proven ground-based systems such as weather radar.

Table A-1. Possible Candidate Requirements for a New Geostationary Operational Weather Satellite System for the Late Eighties

1. Three operational spacecraft based upon the 1980 two-VISSR plus experimental VAS configuration.
2. Improved multi-channel visible/IR imaging with high-resolution in all channels (1 km or better), improved dynamic response, and improved calibration.
3. Multi-channel microwave imaging at 5-10 km resolution.
4. Advanced atmospheric sounder with microwave subsystem for improved thermal and moisture resolution.
5. Simultaneous capability for sounder, imager, secondary sensor, and full communications operations.
6. Capability for precise inter-satellite image synchronization for stereo operations.
7. Advanced spaceborne computer for ground reprogrammable, on board pre-processing.
8. Advanced communications package to: acquire and relay preprocessed remote platform data; acquire and relay data from polar orbiter satellites; provide realtime rebroadcast of preprocessed information optimized for the monitoring and nowcasting of severe weather developments and in a signal suitable for direct acquisition by small-antenna, low cost ground stations.

These and other ideas, under consideration by the NOAA and NASA planners, provide the basis for possible requirements for the new polar orbiters as expressed in Table A-2.

A.3 Advanced Ground Processing Support

Since the integrated systems approach is being used in designing the new operational system, an important consideration is appropriate ground data handling facilities. As with other components, one must review present state-of-the-art capabilities and make realistic projects for facilities capable of handling the increasing processing load in a timely manner. But alternative solutions become complicated if we project on-board preprocessing and easier direct access. With the marked trend toward more powerful computers at lower cost, one may visualize product extractions for a variety of specialized users in a distributed processing arrangement. And whether the specialized users are collocated or scattered will likely depend upon overlapping common interests, final customer interfacing logistics and other factors. In the case of aviation weather, interdependence between satellites and so-called conventional weather usage in fine scale weather prediction and other related severe weather support activities, will likely favor continued NESS/NMC sharing of the large-scale computers projected as replacements for the present 360/195 machines. However the processing system is configured, the demands for timely digestion of larger masses of basic data will increasingly involve specialized array processor and vector logic machines. Present offerings bespeak the growing emphasis, and, with ongoing developments, one can anticipate adequate capability for increasing product extractions.

Timely product services also depend upon improved mass storage of digital data. The 665K bps TIROS-N data flow and the present 1.2M bps output from each GOES spacecraft will both be replaced by satellites with substantially higher data rates in the new system. With advancements in magnetic bubbles, charge coupled devices, and laser storage technology, new mass memory facilities with higher bulk capacity and better on-line performance characteristics should soon be available as replacements for present systems such as the magnetic tape TBM system. One recent study (Heard, 1977) projects optical storage densities of 10^{10} bits/square inch and read/write bandwidths in the gigahertz range.

One likely projection for a late eighties central processing system for NOAA could be patterned after that currently being considered at AFGWC. A very wide bandwidth data bus would link all specialized mission work stations concerned with the handling of conventional weather data, digital weather radar data, numerical weather prediction, and satellite data manipulation and product

Table A-2. Possible Requirements for a New Polar Orbiter Series

1. Modular construction with simple shuttle demount and exchange capability for component repair or upgrade.
2. Active/passive microwave imager.
3. More frequent global coverage (one suggestion: 3-hourly with 8 spacecraft).
4. Active weather radar and lidar sensing.
5. Integrated scanning for improved concurrent footpad registry of all sensors.
6. Advanced onboard preprocessing for: radiometric correction, geometric correction (panoramic, earth rotation and other corrections), and navigated earth location of all relayed sensor data.
7. Synthetic aperture radar.

extraction. Computing resources commensurate with each mission would be locally available to support each task. Array devices, optimized for specific tasks would perform numerical model integrations and manipulative product extractions from satellite image data. And a very large multi-unit data base would be on line to all users -- those work stations tasked with entry of new information into the data base, and others which extract and format information for user dissemination. Such a system can grow in an evolutionary manner, using any hierarchy of processing devices so long as each component adheres to the data bus protocol. Once the protocol is established, external users can communicate and receive products with assurance that interface arrangements will not be affected by internal hardware augmentation or other alterations made within the processing complex.

A.4 Other Late Eighties Satellite Developments

One would likely be ill-advised to attempt projection of the DMSP into the late eighties. The program must be responsive to weaponry development and to mission changes. Therefore, possible access and service to civilian users must properly be relegated to lower priority status. As for improvements in sensors, image data handling, and communications, an advanced system beyond Block-5D might be the first operational weather satellite to profit directly from related military technology developments. Considering likely constraints, interfacing to AWES appears to require continued active coordination through channels such as the interagency Subcommittee on Operational Meteorological Satellites (SCOMS).

In the case of oceanographic satellite interfacing, uncertainties in the present program also makes this a most speculative subject for late eighties projections. If the advancing program continues under NOAA direction, it might possibly become integrated into the new polar orbiter series. In any case, it would seem that early microwave sensing, which suggests possible AWES interest in SEASAT, will no longer provide impetus for oceanographic satellite interfacing. By the late eighties, AWES application interest will have become more firmly established and appropriate instrumentation included in the new polar orbiter weather satellites.

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